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Dated 21st July, 1999

PATENTS FORM 1/77

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REQUEST FOR THE GRANT OF A PATENT

THE GRANT OF A PATENT IS REQUESTED BY THE UNDERSIGNED ON THE BASIS OF THE PRESENT APPLICATION

1 Title of invention: DIAGNOSTIC SENSOR

2 Applicant's details

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4 Agent's reference: 104841

5 The application claims an earlier date under Section 8(3), 12(6) 15(4) or 37(4):

Yes or No: No

Earlier application or patent number:

and filing date:

6 Declaration of priority

None

7 Inventorship

The applicants is/are the sole inventor or joint inventors

Yes or No: No

8 Check List

A	The application contains the following number of sheets:			B	The application as filed is accompanied by:
1.	Request	1	sheets	1.	Priority document: No
2.	Description	3	sheets	2.	Translation of priority document: No
3.	Claims	0	sheets	3.	Patents Form 7/77: No
4.	Drawings	4	sheets	4.	Patents Form 9/77: No
5.	Abstract	0	sheets	5.	Patents Form 10/77: No

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9 Signature for BOWLES HORTON

This invention is concerned with the use of a vibrating resonant structure for the measurement of physical and chemical properties of fluids and solids.

1. SENSOR DESIGN

This embodiment is described as an example to illustrate the principles employed in the invention.

Two beams are rigidly connected at their extremities. The yokes formed at the extremities have a high stiffness and the beams are therefore referred to, in the terminology of modal beam analysis, as 'clamped'.

Such an arrangement, referred to as clamp-clamp and shown in Fig. 1, will resonate at a first mode natural frequency given by the equation:

$$f = 22.3733 \sqrt{(EI / ml^4)} \qquad (1)$$

f =	Frequency
E =	Young Modulus
I =	Mass Moment of Inertia
m =	Mass/Unit Length
l =	Beam Length

If the connecting yoke at one end of the arrangement is substantially weakened the beams can no longer be considered clamped, as they are allowed a degree of rotation about their connection point; in the terminology of modal beam analysis the yoke is then approaching the pinned condition. This arrangement is shown in Fig. 2, and the clamp-pinned system will now resonate at a natural frequency given by the equation:

$$f = 15.4182 \sqrt{(EI / ml^4)} \qquad (2)$$

From equations (1) and (2) it can be seen that the transition from fully clamped to fully pinned results in an approximately 30% change in frequency.

In addition to a change in frequency the modal shape of the clamp-clamp system differs significantly to the clamp-pinned arrangement. A generalised view of the displacement of the beam in each mode is shown in Fig. 3. In addition, Fig 4 shows the generalised view of the distribution of local beam bending with respect to position on the beam. A sensor responding to localised beam flexure, such as a piezoelectric device, would show a signal response with length similar to the profiles shown in Fig 4. As well as a voltage amplitude profile with length there can also be observed a polarity, or phase change, of the vibration signal along the length.

In summary, the transition from clamp-clamp to clamp-pinned results in changes in frequency, amplitude and phase of vibration relative to position on beam. The measurement of change of

these parameters in response to an event influencing the modal classification of the resonator (i.e. clamp-clamp to clamp-pinned) forms the basis of this invention.

2. WEB MODIFICATION

In applications, where there is depletion of a substrate or build-up of material, such as corrosion or scaling, the actual substrate may form a stiffening member on the beam yoke and thus contribute to the status of the yoke as clamped or pinned.

Fig. 5 shows a simple embodiment of a dual beam system. Depletion of material at a connection nexus will drive the yoke into a pinned state. However such a system would require significant depletion of material to manifest a modal change.

Improvements on this are shown in Fig. 6 and Fig. 7; in both these cases the solid connection is replaced by a box section forming a rigid web. The web achieves its stiffness from spatially configured thin members, and a small reduction of thickness of a part of each member will manifest a substantial change in rigidity - thus altering the yoke stiffness.

Fig. 6 shows an arrangement where the rigidity of the web is modulated by the longitudinal stiffness at the point indicated 'A'. Fig. 7 shows the sections marked 'B' which will significantly influence web rigidity if their flexural stiffness is altered.

Fig. 8 is a refinement of Fig. 6 which allows for a 'bolt-on' web stiffener to be used. This forms a convenient means of selecting the material, shape and size of a web member to suit a particular application.

3. EMBODIMENTS

Expanding the embodiment of Fig. 8, an arrangement is shown in Fig. 9 where piezo electric transducers are strategically placed to indicate the amplitude and phase of the flexure of the beam at a specific location. The signal from each transducer relates directly to the modal pattern formed by the clamp or pinned condition of the yoke; these relative voltages are shown on the corresponding modal graph of the beam, also shown.

Fig. 10 shows how the amplitude and phase of voltage from each piezoelectric sensor, and the natural frequency of the resonator are altered by the decreasing stiffness of the web forming the yoke. It follows that the progress of any physical, chemical, or biological effect leading to the depletion or build-up of the sacrificial web material can be monitored by measuring the modulation of these piezoelectric sensor signals over time. As an example, a web stiffener made from iron will deplete its thickness, and hence stiffness, in a corrosive environment over time and measurement of Va, Vb or frequency will indicate the rate of corrosion. It follows that selection of other materials in the electrochemical series can exhibit the same corrosion/deposition effects in the appropriate electrolyte

Resonators are driven into resonance at the natural frequency using a piezoelectric, or magnetic, device mounted a vibrationally efficient point and driven by a positive feedback loop from one of the pick-up sensors.

Signal processing techniques, such as the following, can be employed to enhance the result:

a) Division of Va by Vb will result in a ratio dependent on web stiffness but independent of amplitude of signals or system damping.
b) Division of Va or Vb by Vref will result in a ratio dependent on web stiffness but independent of amplitude of signals or system damping.
c) Measurement of phase of Vb will form a simple method of indicating the point at which a specific web stiffness is reached.
d) A number of piezoelectric sensor mounted along the beam can be monitored for change of phase to indicate progress of change of web stiffness.
e) If the resonator is at full temperature equilibrium with its environment the modal shape will indicate web stiffness independently of temperature.
f) Frequency signal has some temperature dependency so comparison of modal shape with frequency signal will yield both temperature and web stiffness from a single resonator.

In general terms the invention can be a force transducer. With the web removed the stiffness of the pinned yoke will be altered towards the clamped state by the presence of an external force on the yoke, either in compression or tension. These forces can be mechanical, electrical or magnetic.

The movement of the arms of the yoke will create a velocity and therefore shear within a fluid. By measuring energy loss, or Q, of the signal the viscous shear loss can be determined, and thus the fluid viscosity.

Similarly, the damping capacity of any solid connected to the yoke can be determined from the Q of the resonant signal.

Further embodiments are possible such as the free-clamp transducer shown in Fig. 12. A convenient clamp-clamp arrangement is shown in Fig. 13 which has one beam contained within another. A further version shown in Fig. 14 has a clamp-pinned resonator operating with longitudinal vibration.

All resonators can be operated in harmonic modes above the natural frequency. There are proportional movements in modal/frequency behaviour at higher modes to that at fundamental.

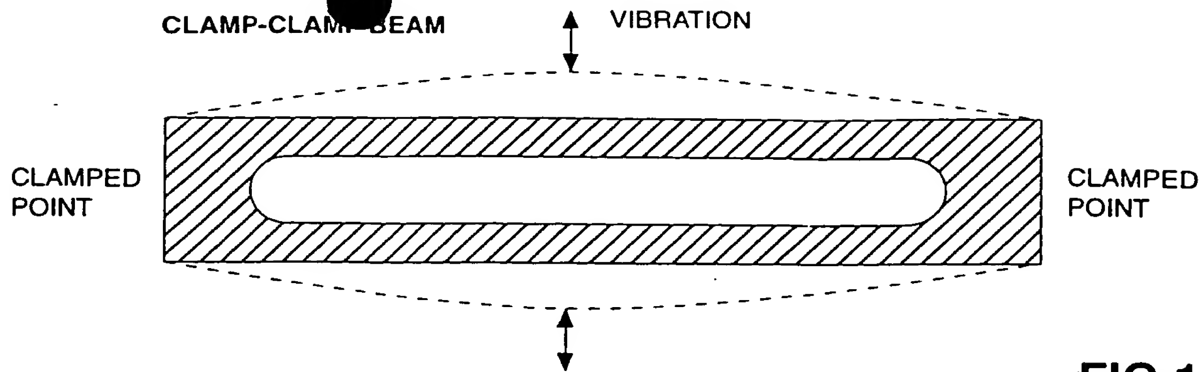


FIG 1

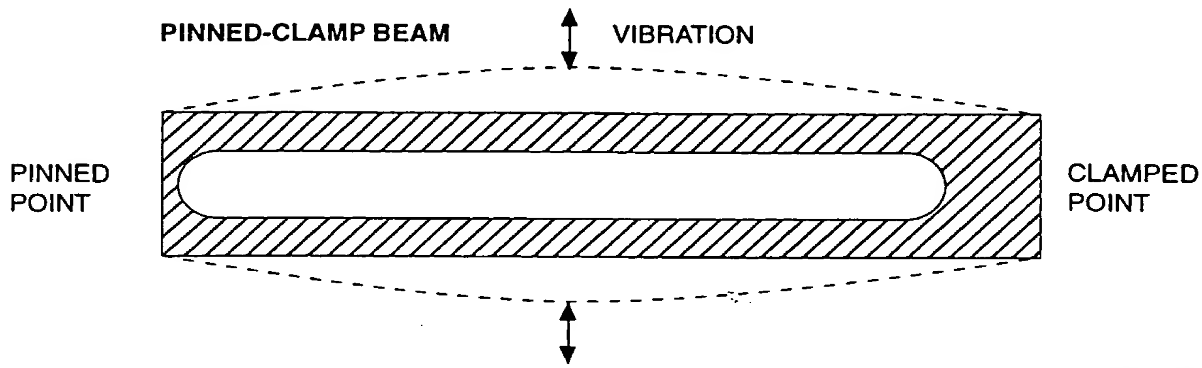


FIG 2

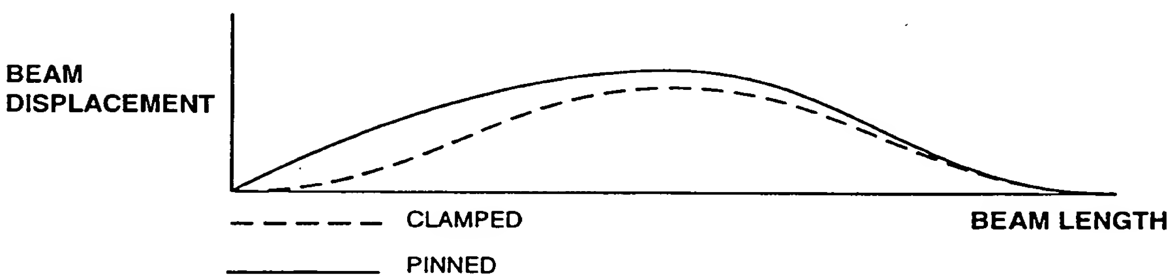


FIG 3

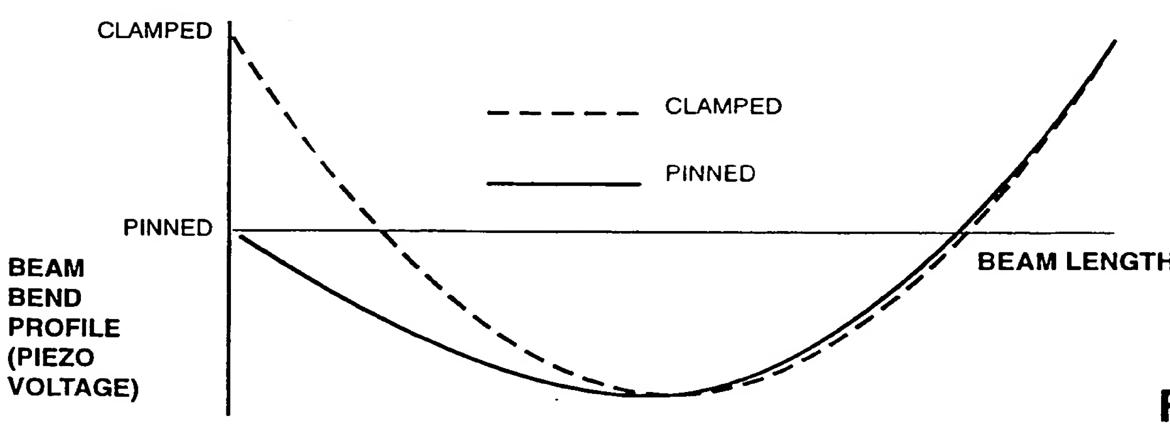


FIG 4

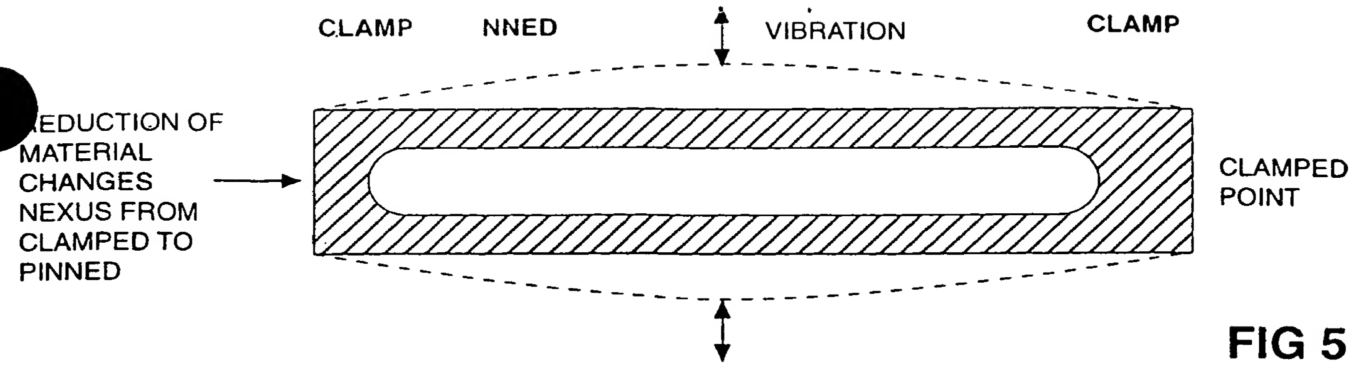


FIG 5

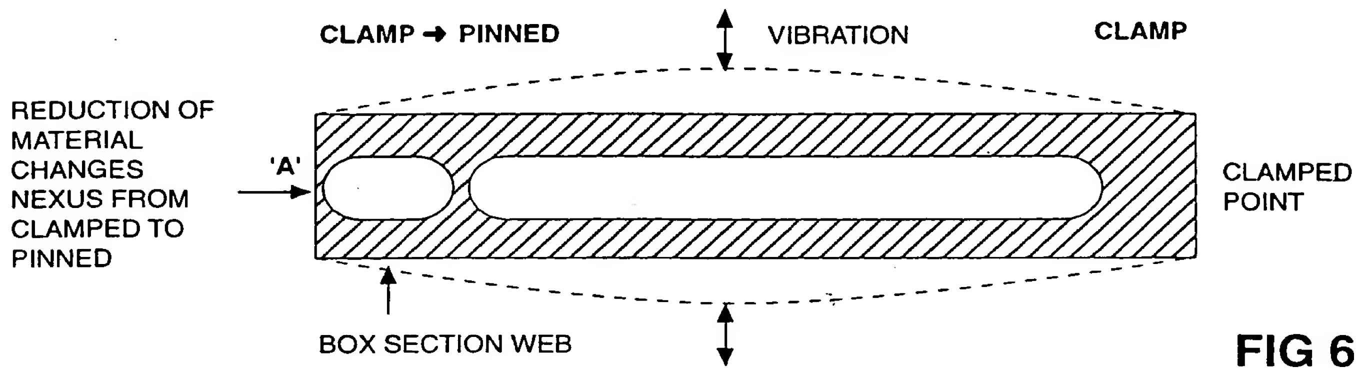


FIG 6

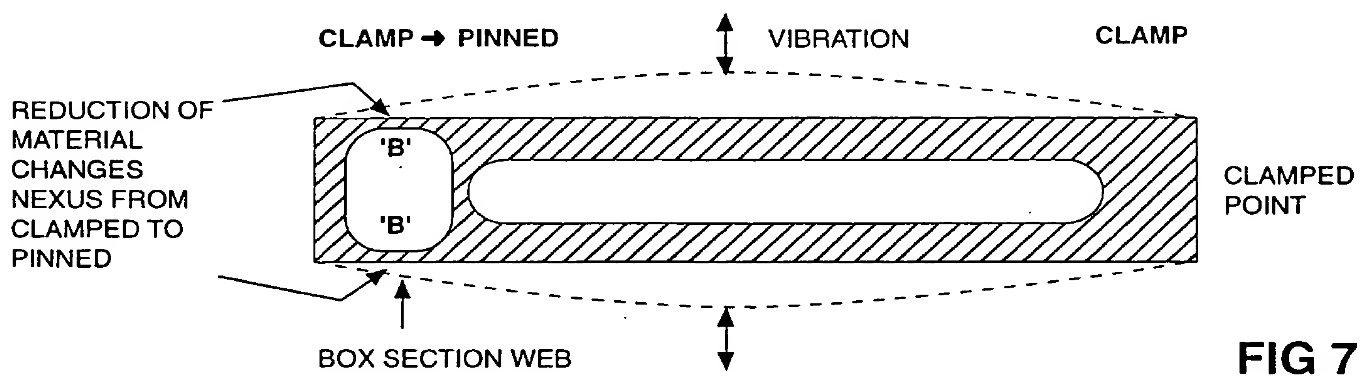


FIG 7

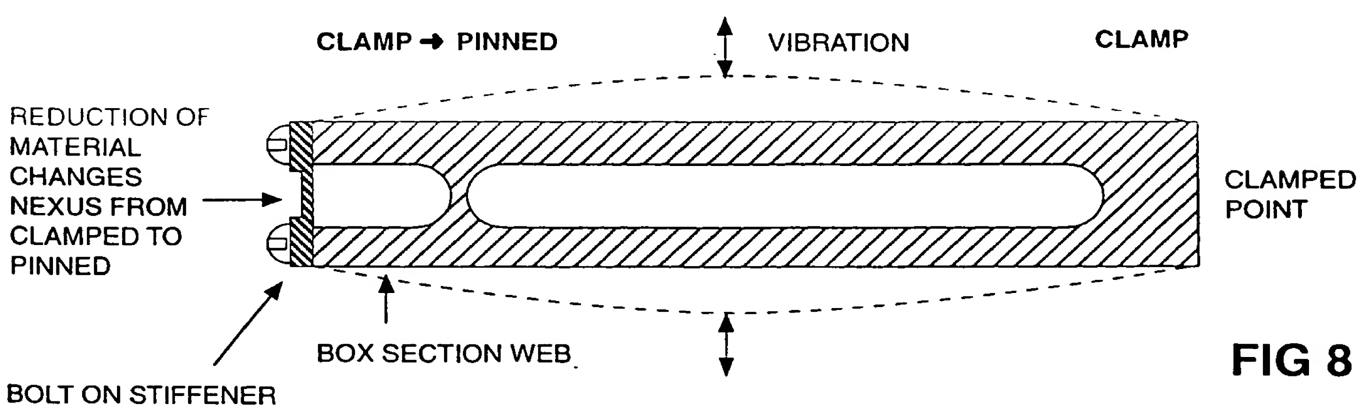


FIG 8

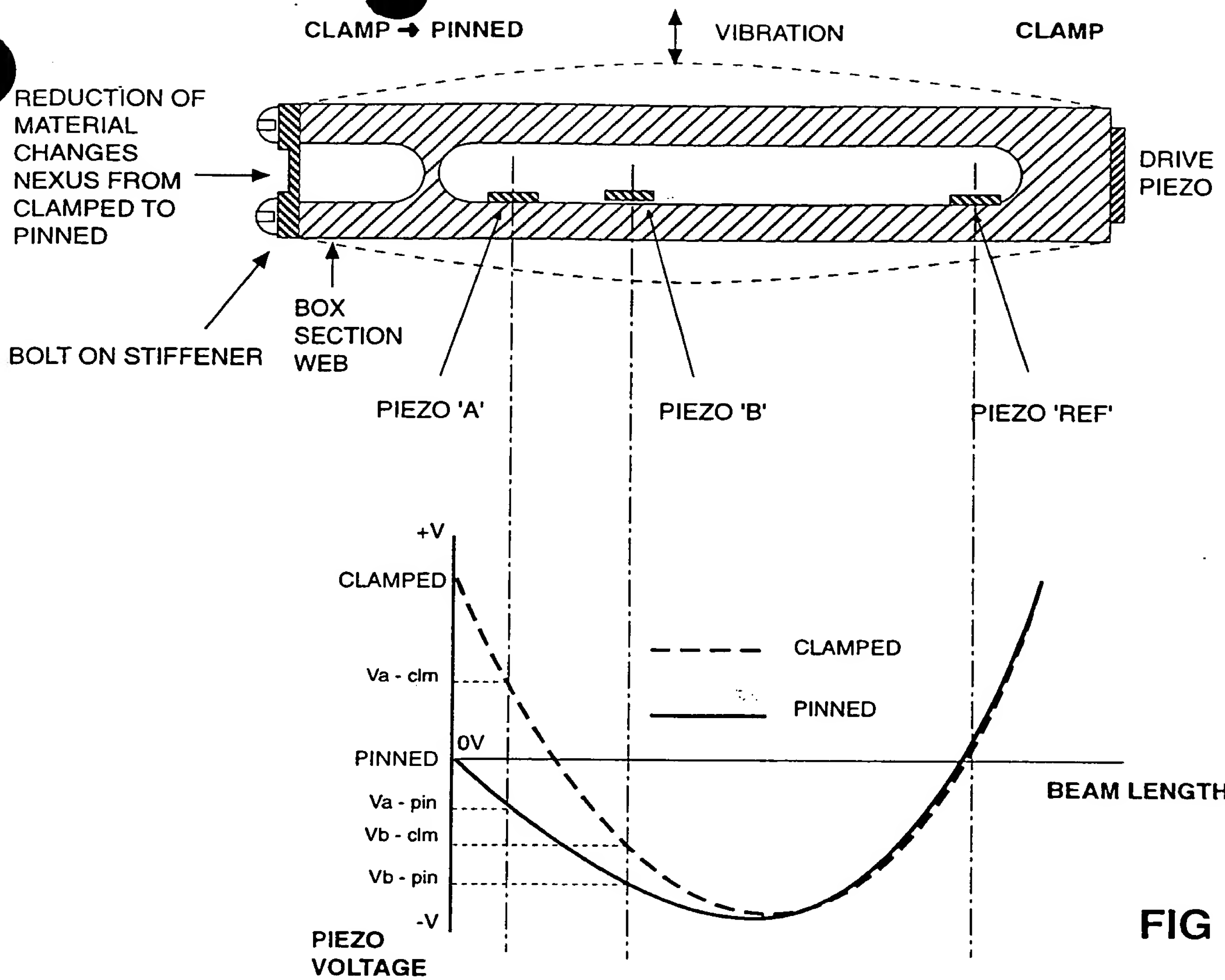

CLAMP → PINNED
VIBRATION
CLAMP
REDUCTION OF MATERIAL CHANGES NEXUS FROM CLAMPED TO PINNED
DRIVE PIEZO
BOX SECTION WEB
BOLT ON STIFFENER
PIEZO 'A'
PIEZO 'B'
PIEZO 'REF'
+V
CLAMPED
Va - clm
CLAMPED
PINNED
0V
PINNED
Va - pin
Vb - clm
Vb - pin
-V
BEAM LENGTH
PIEZO VOLTAGE

FIG 9

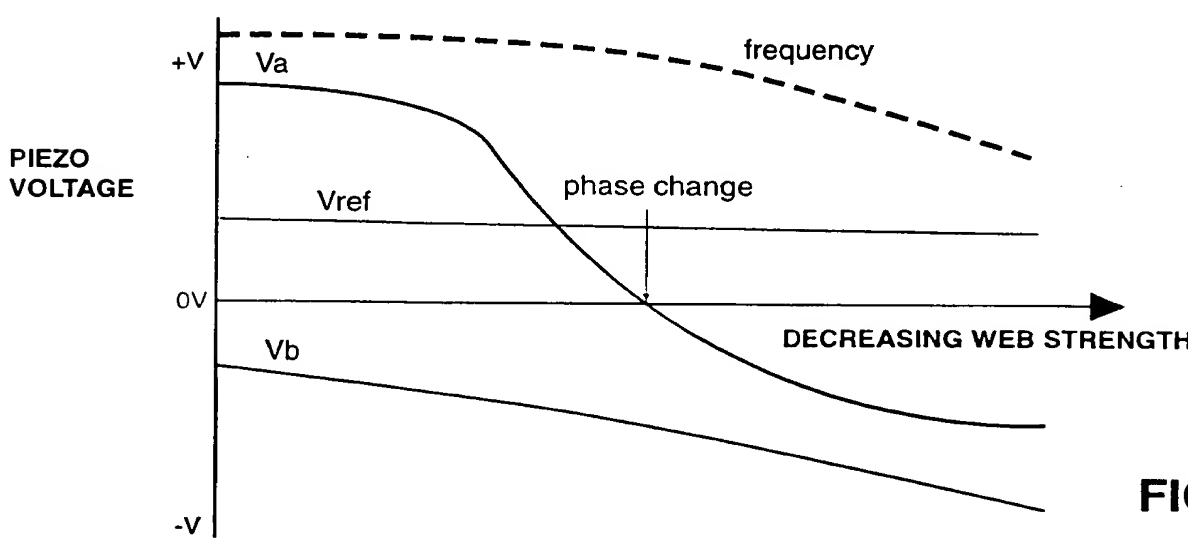
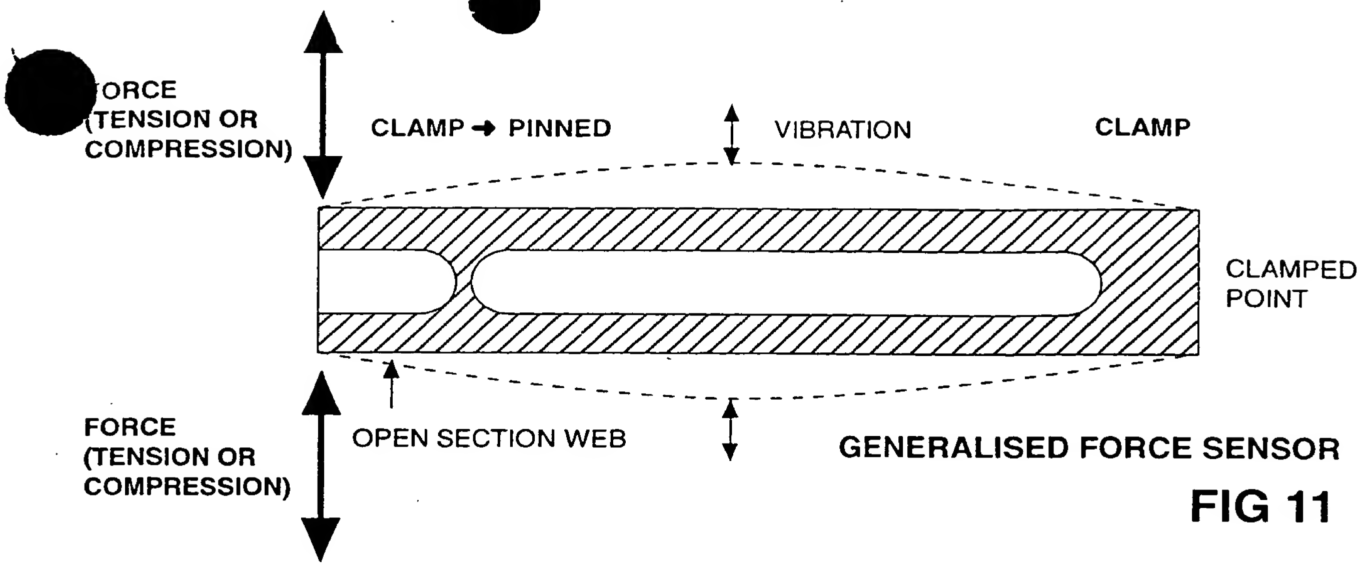

+V
Va
frequency
PIEZO VOLTAGE
Vref
phase change
0V
Vb
DECREASING WEB STRENGTH
-V

FIG 10



GENERALISED FORCE SENSOR

FIG 11

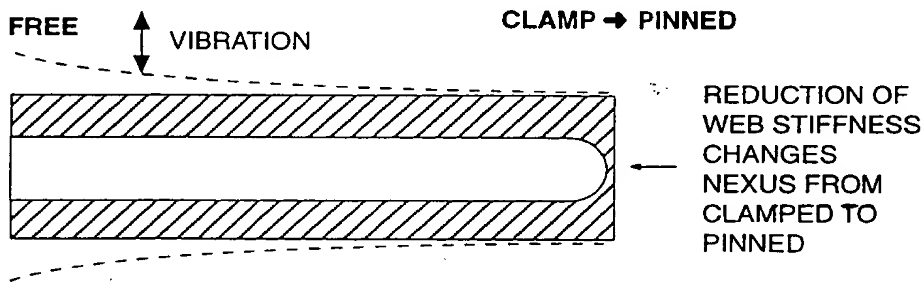


FIG 12

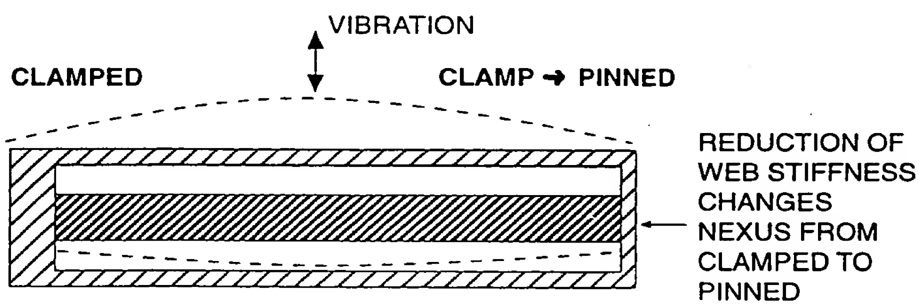


FIG 13

SECTION THROUGH CYLINDRICAL BEAMS

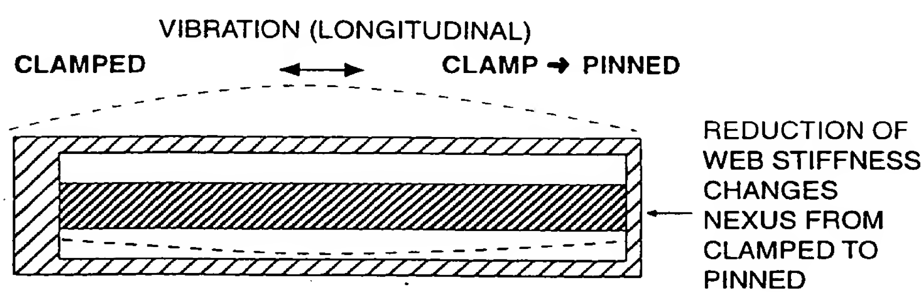


FIG 14

SECTION THROUGH CYLINDRICAL BEAMS